Stratospheric Aerosol and Gas Experiment (SAGE) III
Data Validation Plan

C. Trepte
NASA Langley Research Center
Hampton, VA 23681

LaRC 475-00-020

Version 3.0

April 24, 2000

Signature on file

M. Patrick McCormick
SAGE III Principal Investigator

Signature on file

W. P. Chu
SAGE III Project Scientist

TABLE OF CONTENTS

1. INTRODUCTION

The Stratospheric Aerosol and Gas Experiment III (SAGE III) is a critical part of the Earth Observing System (EOS) (EOS Science Plan, 1999; EOS Reference Handbook, 1999). The EOS mission is to develop an understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. SAGE III provides limb occultation measurements with a flexible instrument design that permits on orbit reprogramming and channel selection with up to 800 channels spanning the ultraviolet, visible, and near infrared (280-1040 nm). Solar observations will provide high resolution vertical profiles of multi-wavelength aerosol extinction, the molecular density of ozone, nitrogen dioxide, and water vapor, as well as profiles of temperature, pressure, and cloud presence. In addition, the inclusion of a repositionable solar attenuator will allow lunar occultation observation that will improve the geographic coverage and permit measurements of nitrogen trioxide and chlorine dioxide in addition to ozone, nitrogen dioxide, water vapor, and pressure.

1.1 Purpose and Scope

This Validation Plan outlines an approach to verify the SAGE III measurement and retrieval algorithm system and a strategy to acquire correlative measurements in order to validate the accuracy and precision of the SAGE III Standard Science Products. The plan covers the first 2 years of operation (November 2000 - October 2002) of the SAGE III/Meteor-3M mission. A second SAGE III instrument will be placed on the International Space Station (ISS) in 2003. Validation plans for the ISS/SAGE III instrument will be included in a future revision of this document.

The original SAGE III Validation Plan was first submitted in 1997 and has been modified as plans were developed to obtain correlative measurements during different field campaigns. Unfortunately, launch of the SAGE III/Meteor-3M mission has been delayed on a number of occasions and has resulted in major setbacks in the design and implementation of a SAGE III Validation Plan. The most significant setback resulted from missed correlative measurement opportunities during the SAGE III Ozone Loss and Validation Experiment (SOLVE) in the winter of 1999-2000, which was partially designed to support the validation of SAGE III and other satellite instruments. Plans for future aircraft correlative measurement opportunities will be developed in cooperation with NASA’s Upper Atmospheric Research Program and will be included in revisions of the SAGE III Validation Plan.

1.2 Applicable Documents

1.2.1 Controlling Documents

1999 EOS Reference Handbook; A Guide to NASA's Earth Science Enterprise and the Earth Observing System, EOS Project Science Office, Code 900, NASA/GSFC, NP-1999-08-134-GSFC, 1999.

1.2.2 SAGE III ATBD Documents

SAGE III Algorithm Theoretical Basis Document: Transmission Data Products, LaRC 475-00-108, February 2000.

SAGE III Algorithm Theoretical Basis Document: Temperature and Pressure Data Products, LaRC 475-00-104, February 2000.

SAGE III Algorithm Theoretical Basis Document: Aerosol Data Products, LaRC 475-00-105, February 2000.

SAGE III Algorithm Theoretical Basis Document: Nitrogen Dioxide Data Products, LaRC 475-00-101, February 2000.

SAGE III Algorithm Theoretical Basis Document: Nitrogen Trioxide Data Products, LaRC 475-00-102, February 2000.

SAGE III Algorithm Theoretical Basis Document: Chlorine Dioxide Data Products, LaRC 475-00-103, February 2000.

SAGE III Algorithm Theoretical Basis Document: Water Vapor Data Products, LaRC 475-00-100, February 2000.

SAGE III Algorithm Theoretical Basis Document: Cloud Presence Data Products, LaRC 475-00-106, February 2000.

SAGE III Algorithm Theoretical Basis Document: Ozone Data Products, LaRC 475-00-107, February 2000.

1.3 Configuration Control

The SAGE III Validation Plan is maintained by the SAGE III Science Computing Facility (SCF) and managed under the SAGE III SCF Software Configuration Management Plan, LaRC 475-03-120. The approved version of the SAGE III Validation Document will be available at URL: **http://eospso.gsfc.nasa.gov/validation/sageval.html**

1.4 Revision History

The original version of this document was dated July 15, 1997. Version 2.0 was released on April 1, 1999. This release, version 3.0, is dated April 24, 2000.

2. MISSION OVERVIEW

2.1 Science Objectives

Atmospheric ozone is an important greenhouse gas present in both the troposphere and stratosphere. It shields the Earth's environment from harmful ultraviolet radiation, but also acts as a major oxidizing species and can affect the lifetimes of many chemical species in the atmosphere. Ozone also absorbs and emits radiation in several wavelength ranges and plays a prominent role in the radiative balance of the climate. A principal goal of SAGE III is to accurately and precisely determine spatial and temporal distributions of ozone and some of those species (NO_2, NO_3, and OClO) that affect its distribution. Profile measurements by SAGE III will provide crucial information on trends, particularly around the tropopause where radiative forcing is sensitive to changes in ozone.

Atmospheric aerosols also influence the radiative balance of the Earth's climate, not only by affecting the amount of radiation absorbed and emitted, but also by altering the optical and physical properties of clouds. It is well known that the injection of volcanic aerosols into the stratosphere can cause significant radiative forcings that last a few years. However, it has only recently been recognized that volcanic aerosols can be linked with changes of stratospheric ozone and that these effects must be accounted for in ozone trend analysis. Lower in the atmosphere, enhanced aerosol levels in the troposphere may have a more profound radiative impact than those from volcanic eruptions, especially as industrial activity increases in developing countries. SAGE III measurements can probe the upper troposphere and provide insight in a region where aerosol observations are scarce. These measurements will extend the ~20 year global aerosol record made by the SAGE family of instruments and provide valuable information on the aerosol distribution and their evolution.

SAGE III will also provide profile measurements on water vapor and clouds. Since water vapor is the principal greenhouse gas in the atmosphere, information on its vertical and horizontal distribution and trend is important for understanding its subtle influence on climate. The instrument will further provide multi-wavelength measurements of polar stratospheric clouds (PSCs) and subvisible cirrus, which will be useful for understanding their distribution and how they may influence atmospheric chemistry, radiation, and dynamics.

In addition to constituent profiles, SAGE III will obtain temperature and pressure profiles. These measurements are needed to remove dependencies on external sources for this information and to improve the accuracy of the retrieved constituents. Temperature and pressure measurements will be valuable for interpreting SAGE III observations and for addressing outstanding scientific issues such as climate change.

In summary, the experimental objectives for the SAGE III mission are:

- Retrieve global profiles of atmospheric aerosol extinction, temperature, and pressure and molecular density profiles of ozone, water vapor, nitrogen dioxide, nitrogen trioxide, chlorine dioxide with 0.5 km vertical resolution;

- Determine long-term trends in aerosol extinction, gaseous species and temperature;

- Characterize tropospheric as well as stratospheric clouds and investigate their effects on the Earth's environment, including radiative, microphysical, and chemical interactions;

- Provide atmospheric data essential for the interpretation and calibration of other satellite sensors, including EOS instruments; and

- Investigate the spatial and temporal variability of these species in order to determine their role in climate processes, biogeochemical cycles, and the hydrological cycle.

2.2 Instrument Background

SAGE III provides limb occultation measurements with a flexible instrument design that permits on orbit reprogramming and channel selection of a charge coupled device (CCD) with up to 800 channels spanning the ultraviolet, visible, and near infrared (280-1040 nm). A single photodiode will add aerosol extinction measurements at 1550 nm. Solar observations will provide high resolution vertical profiles of multi-wavelength aerosol extinction, the molecular density of ozone, nitrogen dioxide, and water vapor, as well as profiles of temperature, pressure, and cloud presence. The inclusion of a repositionable solar attenuator will permit lunar occultation observations of nitrogen trioxide and chlorine dioxide, in addition to improved geographical coverage of O_3 and NO_2. For solar occultation events, the instrument has a 0.008° vertical field-of-view and a 0.025° horizontal field-of-view. For lunar occultation events, the instrument uses a horizontal field-of-view of 0.041°.

The fundamental aspect of the satellite experiment is the measurement of atmospheric transmission along the satellite-sun (or moon) line-of-sight (LOS) during each occultation event (see Fig. 1). As the sun or moon ascends or descends behind the Earth, the instrument scans continuously across the solar (or lunar) disk and multiple transmission measurements are made at each tangent altitude. Each measurement event takes about 2-4 minutes to complete. The irradiance measurements are normalized by those measurements made outside the atmosphere, from which a transmission profile is then constructed with a vertical resolution of about 1/2 km. The retrieval of individual constituents depends upon the separation of the relative absorption and scattering contributions of atmospheric species at different wavelengths. A basic assumption of the algorithm retrieval is that the atmosphere is horizontally homogeneous within a 1/2 km layer on scales of at least 200 km. For many situations, this is probably a good assumption for most stratospheric constituents, but is not always true for cloud and may well be a poor approximation for other constituents in the troposphere. Details on the algorithm retrieval are provided in the Algorithm Theoretical Basis Documents (ATBD), which are available at the URL: http://eospso.gsfc.nasa.gov/atbd/sagetables.html.

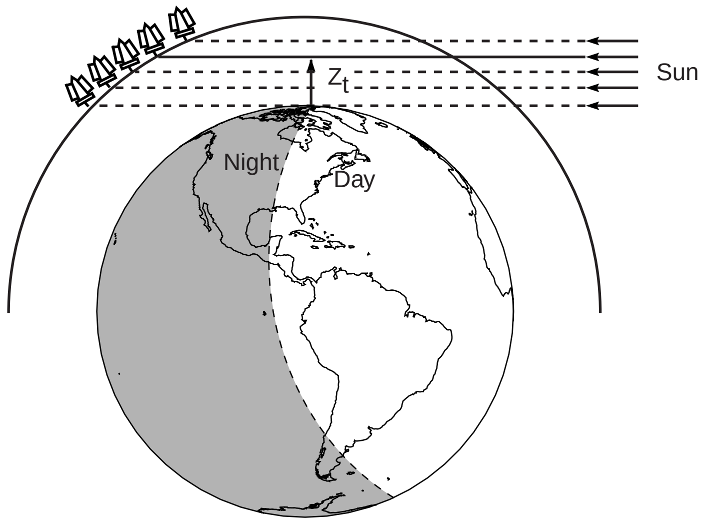

Figure 1. A sunset occultation event as viewed by the satellite. The instrument scans the solar disk at the tangent height (Z_t) and follows it until the sun is obscured. Different layers of the atmosphere are successively sampled during the event (see McCormick et al. (1979) for a general overview of solar occultation technique).

2.3 Launch Dates and Orbit Coverage

The SAGE III experiment consists of two missions designed to acquire global coverage over a multi-year period: launch on board a Russian Meteor-3M spacecraft is tentatively scheduled for November 2000 and integration of an instrument on board the International Space Station in 2003. For high latitude coverage, the Meteor-3M spacecraft will be placed into a polar, sun-synchronous orbit at an altitude of approximately 1020 km and inclination of 99.5°. The spacecraft will have a nominal equatorial crossing of 9:15 am, with an expected lifetime of at least 3 years. Low and mid latitudinal coverage will be provided principally by a SAGE III instrument mounted on the International Space Station (ISS). The ISS orbit will be inclined at 51.6° at an altitude of ~350 km.

The nominal time-latitude coverage of local satellite occultation events for the SAGE III/Meteor-3M missions is displayed in Fig. 2. For this mission, satellite sunrise events will occur between ~35° S and ~60° S, while sunset events will take place between ~50° N and ~80° N. Lunar events will vary from pole-to-pole. Note that the motion of the sun at the surface, however, may differ from that experienced by the satellite (e.g. a sunrise may occur to an observer at the surface during a satellite sunset event). A list of predicted SAGE III solar and lunar measurement locations covering a period of 6 months will be provided on the SAGE III homepage (http://www-sage3.larc.nasa.gov) and updated each quarter to facilitate the acquisition of correlative measurements for SAGE III data comparisons.

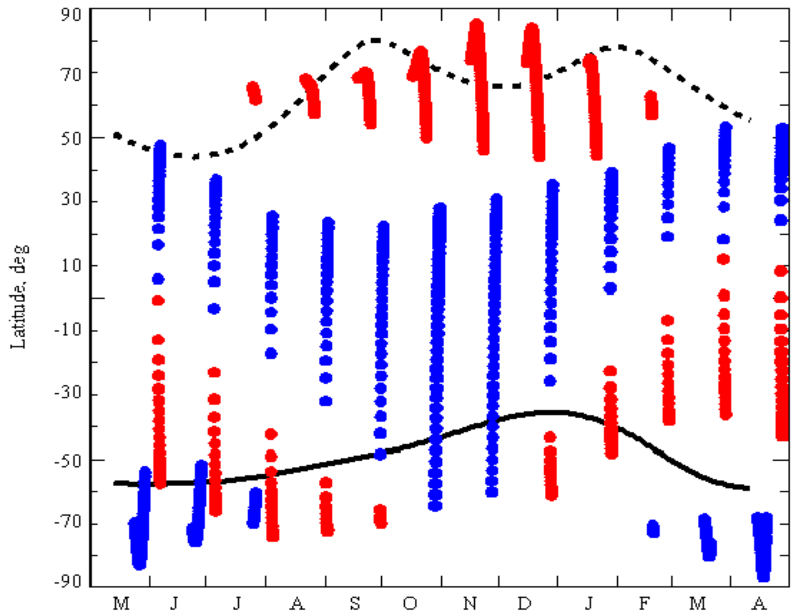

Figure 2. Nominal SAGE III/Meteor-3M time-latitude measurement coverage for May 2001 through April 2002. Local satellite sunrise (sunset) occultation events are denoted by solid (dotted) lines. Moonrise (moonset) occultation events are indicated by red (blue) dots. *Although the expected launch date for the Meteor-3M spacecraft has been delayed until November 2000, the sampling coverage for the SAGE III solar events should closely resemble this displayed pattern over the course of a year. The lunar measurement pattern, however, will shift earlier or later in time depending upon the launch date. This figure will be updated after a new set of predicted satellite state vectors is received from the Russian Space Agency several months before launch.*

2.4 Science Data Products

Table 1 lists the Level 1B and 2 Standard Science Products to be produced for each occultation event opportunity, assuming penetration of the signal through the particular layer of the atmosphere. The anticipated accuracy, precision, profile range, and vertical resolution are also provided for each product. Vertical profiles will extend upwards from the boundary-layer or cloud top, which ever is higher. These products will be available at the NASA Langley Research Center (LaRC) Distributed Active Archive Center (DAAC) approximately 3 months after commencement of instrument operation. Real-time data products will also be available at the SAGE III homepage (http://www-arb.larc.nasa.gov/sage3). In addition to the Standard Science Products, a number of related Research Science Products such as aerosol surface area and mass will be produced and evaluated by the SAGE III Science Team before being distributed to the general science community. A strategy to validate a few of the Research Science Products is included in this plan.

Table 1. SAGE III Standard Science Products

Product Name	Accuracy/Precision	Vertical Resolution/Range
Level-1 B Transmission profiles (< 80 wavelengths)	0.05%:0.05%	0.5 km:0-100 km
Aerosol extinction profiles and stratospheric optical depth (@ 8 wavelengths)	5%:5%	0.5 km:0-40 km
H_2O Concentration (altitude) Mixing ratio (pressure)	10%:15%	0.5 km: 0-50 km
NO_2 Concentration (altitude) Mixing ratio (pressure) Slant path column amt.	10%:15%	0.5 km: 10-50 km 24 levels/decade: 250-0.8 hPa 0.5 km: 10-50 km
NO_3 (lunar only) Concentration (altitude) Mixing ratio (pressure)	10%:10%	0.5 km: 20-55 km 24 levels/decade: 50-0.4 hPa
O_3 Concentration (Altitude) Mixing ratio (Pressure) Slant path column amt.	6%:5%	0.5 km: 6-85 km 24 levels/decade: 500-0.004 hPa 0.5 km: 50-85 km
OClO (lunar only) Concentration (altitude) Mixing ratio (pressure)	25%:20%	0.5 km: 15-25 km 24 levels/decade: 121-25 hPa
Pressure	2%:2%	0.5 km: 0-85 km
Temperature (altitude and pressure)	2 K:2 K	0.5 km: 0-85 km 24 levels/decade: 1000-0.004 hPa
Cloud presence	N/A	0.5 km: 6-30 km

3. VALIDATION OVERVIEW

3.1 Approach

The SAGE III validation program will be based upon an analysis of the retrieval algorithm and comparisons using SAGE III instrument and engineering data and external correlative measurements. The retrieval algorithm analysis will include an evaluation of the soundness of the retrieval process through a comparison of results from a forward model with those from the inverse retrieval algorithm. This effort will permit consistency checks along major milestones of the retrieval process and will allow it to be evaluated under different simulated atmospheric conditions. Another effort will center upon a self-consistency analysis of different retrieval techniques for the same parameter; (e.g., determination of aerosol extinction using the method utilized by SAGE I/II (Chu and McCormick, 1979) and a multiple linear regression technique identified in the ATBD. The large number of radiance measurements available from different CCD channels will also permit inversion retrievals to be performed using combinations of different radiance channels. Not only will this activity provide insight into the robustness of the selected retrieval method, it will provide information on the instrument performance and retrieval error propagation. Self-consistency analysis will be performed when appropriate such as between solar and lunar occultation events when these events occur at similar latitudes.

External measurement comparisons with SAGE III will be conducted with independent correlative measurements of sufficient number and of known quality to validate the expected accuracy of the SAGE III Standard and Research Science Products. The use of correlative measurements requires knowledge of their accuracy and precision. It further requires an understanding of how intercomparisons should be performed as well as knowledge of the representation of their sampling. The term validation implies a level of agreement between independently measured quantities. Agreement is understood when estimates of uncertainty (error bars) between measurements overlap, even though absolute magnitudes may differ by substantial amounts. In a rigorous sense, validation requires that correlative measurements are traceable to accepted measurement standards; however, such standards do not exist for many of the SAGE III measurements. For these cases, validation will be based upon intercomparisons between different measurement techniques to gain confidence on the relative level of accuracy of the SAGE III data products.

An estimate of the precision of the SAGE III measurements will be determined by comparing the observed measurement variance to an independent estimate of the geophysical variance (Cunnold et al., 1984). For SAGE and SAGE II, this technique was employed at low latitudes where planetary and synoptic scale wave disturbances are relatively weak. Since SAGE III/Meteor-3M solar measurements are restricted to mid and high latitudes, an estimate of the measurement precision will be conducted, instead, during the summer months when variations from planetary wave activity should be relatively weak in the lower stratosphere. A science team member (see Table 2) will lead the validation of each SAGE III Standard Science Product. Major findings from these validation studies will be reported in the scientific literature.

The acquisition of correlative measurements will be patterned after the successful SAM II, SAGE I/II, and UARS validation programs (e.g., Russell et al., 1981; Russell and McCormick, 1989; Gille et al., 1996). In situ and remote sensors on the ground, aircraft, balloons, and satellites will obtain correlative data. Efforts will be made to understand the representativeness of the measurements and minimize differences in time and space between SAGE III and correlative measurements. The program is designed to leverage upon low risk, operational measurement activities and to supplement these measurements with airborne and balloon campaigns tailored to specific sampling needs. In addition to these efforts, internal instrument data (e.g. mirror reflectivity, CCD quantum efficiency, spectrometer temperature) will provide crucial information on the performance of the sensor needed to adequately perform validation activities.

Table 2: SAGE III Validation Teams

Aerosol extinction and related products
P. Russell (lead), C. Brogniez, W. Chu, P. Durkee, B. Herman, P. Hobbs, G. Kent, J. Lenoble, V. Saxena, E. Shettle, L. Thomason, C. Trepte
Clouds
G. Kent (lead), V. Ramaswany, L. Thomason, C. Trepte, G. Vali
Chlorine dioxide, Nitrogen dioxide, Nitrogen trioxide
S. Wofsy (lead), w. Chu, D. Cunnold, N. Elanski, L. Thomason, E. Shettle, J. Zawodny, H. Michelson*, S. Sander*
Ozone
D. Cunnold (lead), A. Chernikov, w. Chu, J. Deluisi, V. Mohnen, J. Miller, L. Thomason, C. Trepte, J. Zawodny, C. Lu*, R. Nagatani*, F. Schmidlin*, P. Wang*
Water Vapor
D. Rind (lead), W. Chu, V. Ramaswany, E. Shettle, L. Thomason, E. Chiou*, H. Michelson*
Temperature and Pressure
J. Miller (lead), M. Pitts*, L. Thomason, F. Schmidlin*

* Adjunct members of the SAGE III Validation Team

3.2 Correlative Measurement Sampling Requirements

The sampling needs of the SAGE III validation program are driven by the limb occultation geometry and include, but are not limited to the following:

- obtain vertical profile measurements for each Standard Science Product
- ensure long-term and low risk correlative measurement program with stable and well-characterized instruments over the lifetime of the project
- minimize uncertainties associated with each spatial and temporal coincidence between SAGE III events and correlative measurement opportunities
- examine the inhomogeneity along the line-of-sight, especially in the presence of subvisible cirrus and polar stratospheric clouds
- conduct correlative measurements under different atmospheric conditions
- determine the altitude registration of the transmission profile (resolution < 100 meters)

3.3 Criteria for Coincidence

For correlative measurements to be useful for validation, they must reflect the atmospheric conditions observed by the SAGE III instrument. This places constraints on the allowable separation in time and space between satellite occultation events and correlative measurement opportunities. By arbitrarily setting small coincidence criteria for ground-based or balloon measurements, the number of correlative measurement opportunities is greatly diminished. This in turn leads to an increase in complexity planning and scheduling of resources and cost of conducting correlative measurements activities. Arbitrary large coincidence criteria, on the other hand, confounds the usefulness of these measurements with potentially larger uncertainties in sampling representativeness.

As guidelines for SAGE III validation activities of stratospheric species, the following spatial coincidence criteria have been adopted from the Upper Atmospheric Research Satellite (UARS) correlative measurement program. As a desired target, the SAGE III measurement point should lie within a 250 km radius of the correlative measurement site. An acceptable coincidence is one where the SAGE III observation lies within 500 km of the site. For species whose lifetimes are longer than a few days, an acceptable criterion is to obtain both correlative and SAGE III observations within 6 hours of each other, with 3 hours being adopted as the most desirable goal. For the validation of SAGE III tropospheric species, coincident criteria need to be more stringent as constituent fields have more variability. Under these circumstances, it is probably unreasonable to quantify a coincidence criterion other than to express the need for near simultaneous measurements.

For many ground-based locations, this coincidence criteria is restrictive and will produce a small comparison database because of the low number of SAGE III occultation events available each day and operational constraints imposed on ground-based sensors such as inclement weather. An alternative and promising approach that would enhance statistics for the intercomparison of long-lived species is to link correlative measurements with SAGE III sampling opportunities using forward and backward isentropic trajectories. With this technique, an ensemble of air parcels could be initialized at either satellite or correlative measurement locations and then allowed to disperse using wind information from assimilated meteorological fields. Intersections between trajectories from different measurement platforms within established coincident criteria would form a comparison data set. From these data, Kolmogorov-Smirnov (KS) tests could determine the likelihood that the observed distributions arose from the same parent population (Gibbon, 1985). The KS test is similar to the more familiar Chi-squared test except that the maximum difference between cumulative Probability Density Functions (PDF) between two samples is used instead of the maximum difference between their PDFs. The KS statistic provides a more quantitative measure of the agreement between the correlative observations than either the Student's *T* test or ranked sum tests of means (Gibbons, 1985). A previous intercomparison study using this approach computed trajectories for 10-day periods and employed coincidence criteria of $\pm$ 1 hour, 1° latitude, 10° longitude, and 20 K (Pierce et al., 1997). To aid this type of analysis, the SAGE III Science Team will have access to an archive of isentropic trajectories computed for each SAGE III occultation location.

3.4 Measures of Success

Validation experiments are conducted to evaluate the accuracy of the retrieved parameters derived from SAGE III algorithms with independent correlative measurements. For measurements with Gaussian PDFs, agreement is understood when error bars between different instrument measurements overlap, even though values may differ. For measurements with different PDFs, KS tests provide an assessment of their relative agreement.

It should be realized that validation of a parameter to the expected level of accuracy listed in Table 1 may be deferred until correlative measurement uncertainty associated with atmospheric conditions is reduced. For example, aerosol lidars are expected to provide key correlative measurement information for the validation of SAGE III aerosol extinction profiles in the lower stratosphere. A major source of error in the use of lidar measurements arises from uncertainties in molecular scattering. Under the near-background aerosol conditions present in the stratosphere in late 1999, these uncertainties can dominate over other systematic errors and hinder the validation of the aerosol extinction products to the required accuracy. For this situation, validation of these products may have to be deferred until a volcanic eruption enhances stratospheric aerosol loading with relatively higher aerosol-to-molecular optical scattering cross-sections.

4. PRE-LAUNCH ACTIVITIES

4.1 Forward/Inverse Model Development

A detailed software simulator of the SAGE III experiment is being developed to reproduce major aspects of the spaceborne experiment and verify the retrieval algorithm systems. The simulator is composed of a series of modules, each one being a physical model of either the instrument (e.g. CCD and photodiode characteristics, telescope optics), spacecraft (e.g. orbital elements, scanning mirror characteristics) or the ambient atmosphere (e.g. constituent distributions and spectral properties). The simulator performs a forward transformation from assumed atmospheric constituent profiles (including knowledge of their homogeniety along the LOS) into Level 0 radiometric scanned data. These results are then inverted with the SAGE III retrieval algorithms and their products compared with *a priori* constituent distributions. Use of the simulator also permits detailed inspection of the processing software by examining incremental aspects of the retrieval algorithm. For example, comparisons could be made between the forward and inverse model calculations of the LOS view geometry and tangent altitude, solar and lunar disk crossing time, and construction of the transmission profile. Elements of this validation activity have been successfully used in the analysis of the SAGE II and III retrieval algorithms, with the result being a series of refinements to their respective software processing systems.

Besides performing algorithm verification studies, the simulator will be used to better understand and quantify the effect that clouds have on the retrieval of constituents. Idealized cloud distributions will be simulated and inverted. Additional simulation studies will be performed by introducing inhomogeneities in atmospheric density, pressure, temperature, and trace gas species. Over the next year, airborne correlative measurements of clouds, aerosols, and gases from the SOLVE measurement campaign will be feed into the simulator to produce Level 0 radiance data that can be compared with the POAM III observations. It is hoped that through these types of activities problems associated with clouds in the algorithm retrieval may be identified and better understood.

4.2 Spectroscopy

A review of the current knowledge of the molecular absorption cross sections as it pertains to the SAGE III instrument is presented in Appendix D of the SAGE III ATBDs. The discussion in each appendix is focused on the specific details of the individual molecules measured by SAGE III. The discussion also includes information on the rest of the spectrum where absorption by that species could interfere with the retrieval of other molecules and identifies additional measurement requirements.

One area of support that has benefited the SAGE III mission is a recent set of laboratory measurements of the oxygen A-band spectral region by Dr. L. Brown of the Jet Propulsion Laboratory. For temperature and pressure retrievals, uncertainties in the line widths and intensities are required to be known to within a few percent to achieve the level of accuracy displayed in Table 1. The EOS Validation Program supported this needed laboratory study and is also funding balloon measurements of the oxygen A-band spectral region to help confirm the laboratory measurements. The balloon measurements are planned for April or May 2000.

4.3 Correlative Measurement Studies

The SAGE III Ozone Loss and Validation Experiments (SOLVE) was a comprehensive satellite, airborne (NASA DC-8 and ER-2 aircraft), balloon, and ground-based measurement campaign designed to study processes responsible for lower stratospheric ozone loss at high latitudes during winter and early spring. The campaign took place between November 1999 and March 2000 and was co-sponsored by NASA's Upper Atmosphere Research Program (UARP), Atmospheric Chemistry Modeling and Analysis Program (ACMAP), Atmospheric Effects of Aviation Project (AEAP), and Earth Observing System (EOS) of NASA’s Earth Sciences Enterprise as part of the SAGE III validation program. Details on the SOLVE mission objectives, instrument payloads, participants, and measurement periods are available at SOLVE project URL http://cloud1.arc.nasa.gov/solve/.

Under the original field mission plan, SOLVE was partially designed to provide extensive correlative measurements needed to validate the accuracy of SAGE III measurements and understand many underlying assumptions in its retrieval algorithm. Unfortunately, a delay in the launch of the SAGE III/Meteor-3M satellite instrument until at least November 2000 prevented this opportunity for direct instrument intercomparisons. However, intercomparisons between operational research satellite instruments (e.g., SAGE II, HALOE, and POAM III) and the wide range of in situ and remote sensing instruments that took place during SOLVE permits an assessment of their relative biases. A number of comparison studies will take place during the spring and summer of 2000 and will be reported at a post-mission workshop in late September 2000. Future intercomparisons between these satellites and SAGE III/Meteor-3M will serve as a bridge back to SOLVE intercomparison database.

Measurements also taken during SOLVE can aid our understanding of a number of uncertainties with the retrieval and interpretation of satellite limb measurement techniques. One of the most important of these uncertainties arises from the impact that clouds may have on the retrieval algorithm. To help study this issue, a few aircraft flights acquired specific observations that will be used with the SAGE III instrument simulator. Other valuable data on the inhomogeneity of constituents along the satellite slant path and their impact on the retrieval algorithm will be studied. Data on the performance of various instruments during SOLVE will be very important in planning future validation activities for SAGE III and the EOS CHEM satellite mission.

5. POST-LAUNCH ACTIVITIES

5.1 Strategy and Priorities

The SAGE III correlative measurement strategy embraces a series of observational activities needed to satisfy the validation objectives listed above. It leverages upon ongoing ground-based measurement activities, with little risk and cost to the project. A few of these sites will be augmented with additional instrumentation by the project to ensure a minimum correlative measurement network. Concurrent satellite programs will also provide an important database for assessing biases and precision between spaceborne sensors (e.g. SAGE II and POAM III). It is expected that these satellite measurements will be supplemented by balloon and airborne flights to provide measurements not available by other observational networks.

Because resources are limited, priorities must be identified in order to provide an adequate database for validation. In view of the importance of determining ozone trends in the upper troposphere and lower stratosphere and the need for understanding the impact that aerosols and clouds have on ozone retrievals, this plan emphasizes the collection of correlative measurements required to validate ozone, water vapor, nitrogen dioxide and stratospheric aerosol measurements during the first 2 years of operation. It does, however, provide plans to acquire sufficient measurements to validate other SAGE III products, or at least, perform consistency checks on them.

5.2 Existing Operational Surface Networks

An important component of the SAGE III validation plan is the intercomparison of complementary observations by other measurement programs. This activity will permit ongoing intercomparisons to occur immediately following launch and to continue throughout the lifetime of the mission. Most of the stations participating in these networks have long measurement records and will be funded during the next 2-5 years. Coordination of correlative measurement opportunities from existing instrument networks with SAGE III measurement opportunities will be made through the SAGE III homepage (www-sage3.larc.nasa.gov) and through email notices.

<u>Network for the Detection of Stratospheric Change (NDSC)</u> The NDSC promises to play a central role in providing multi-year observations during the lifetime of each of the SAGE III instruments. Several sites have instrument suites that can provide profiles of most of the SAGE III measurement species. Careful instrument calibration and intercomparison procedures are followed at each site to ensure that small trends can be detected over multiple years (see http://www.ndsc.ncep.noaa.gov).

Because of their location and instrument complement, the NDSC primary sites at Lauder, NZ; Ny Alesund, Norway; Eureka, Canada; and Thule, Greenland have been identified by the SAGE III Science Team as *anchor* measurement sites for the SAGE III/Meteor-3M validation program. The measurement coverage displayed in Fig. 2 for this satellite shows that sunrise events will occur near the latitude of Lauder (~45° S) during November and March. For satellite sunset events, coincident measurement opportunities will take place in late October/early November, February, March, and September near 70°N.

Table 3 lists measurement capabilities from these stations needed for SAGE III validation. It should be noted that other NDSC primary and secondary measurement sites also offer important correlative measurement capabilities for validation of SAGE III/Meteor-3M data products. The NDSC site at Table Mountain, CA, for example, offers the only ground-based measurement of NO_3 available for comparison with SAGE III lunar events.

It is critical that effective communication links are maintained with the NDSC to ensure that correlative measurement opportunities are identified and comparison activities are optimized between teams. Drs. P. McCormick and C. Trepte from the SAGE III Science Team have been granted membership on the NDSC Theoretical Investigation Team to enhance this coordination and have already established contacts with the different sites (more information on the NDSC can be found at http://www.ndsc.ncep.noaa.gov/).

Table 3. Observations Available at Anchor Correlative Measurements Sites

NDSC Site	Measurements
Eureka, Canada (80.1° N, 86.4° W)	ozone, aerosol lidars FTIR (NO_2, HCl, $ClNO_3$, NO column) ECC ozonesondes
Ny Alesund, Norway (78.9° N, 11.9° E)	aerosol, ozone, and temperature lidars solar, lunar, and starlight photometers UV/Visibile spectrometer (O_3, NO_2, BrO, OClO) FTIR (NO_2, HCl, $ClNO_3$, NO column) microwave O_3, ClO ECC ozonesondes temperature, relative humidity sondes
Thule, Greenland (76.5° N, 68.8° W)	aerosol, temperature lidars UV/Visible spectrometer (O_3, NO_2, OClO) FTIR measurements ECC ozonesondes
Lauder, New Zealand (45.05° S, 169.7°E)	aerosol lidars Umkehr ozone profiles UV/Visible spectrometer (O_3, NO_2, OClO) FTIR measurements microwave O_3 and H_2O

World Meteorological Ozonesonde Network Key ozone profile measurements from the WMO ozonesonde network are needed to validate SAGE III observations between about 8 km and 25 km (http://www.tor.ec.gc.ca/woudc/). Identifying and understanding changes in ozone in the lower stratosphere and upper troposphere is a primary measurement objective for the SAGE III satellite experiment. Many of the WMO stations used Electrochemical Concentration Cell (ECC) instruments which are often calibrated against the accepted standard reference technique (ultraviolet photometer) to an accuracy of ±5% and a precision of 5%. Ozone profile measurements are routinely available from the WMO ozonesonde network, which is a confederation of measurement teams from participating nations. Most sites are located in the mid and high latitudes of the Northern hemisphere. Relatively few stations are located in the tropics and mid latitude regions of the Southern Hemisphere (WMO, 1991; Logan, 1999).

Since each nation is responsible for operating and distributing their measurements to the international community, the frequency of ozonesonde flights varies from about once a week to once a month at different stations. The SAGE III project will coordinate with different instrument teams to facilitate the launching of ozonesondes for sites identified as being within the sampling criterion for correlative measurement opportunities. These opportunities will be based upon forecast trajectories using NCEP forecast products and will be led by V. Mohnen of State University of New York at Albany. Approximately 50 supplemental ECC ozonesonde instruments will be provided to NDSC sites at Ny Alesund, Spitsbergen and at Lauder, NZ to ensure that a significant number of intercomparison opportunities will be available for comparison for the first year of operation. Trajectory tools will be employed to enhance the number of comparison opportunities. Using these tools, it is hoped that over 200 coincidences in the northern high latitudes will be available for comparison studies during the first year of operation.

WMO Radiosonde Network The international radiosonde network provides profiles of temperature, pressure (altitude), and relative humidity at stations dispersed around the globe. Measurements are typically made at 0 and 12 GMT. These measurements will be used in the validation of SAGE III temperature and pressure retrievals. Because observations are keyed to these specific periods, no attempt will be made to coordinate special correlative measurement activities with these sites. In the upper troposphere and lower stratosphere, the radiosonde temperature accuracy is reported to be about 2 K.

International Aerosol Lidar Network A confederation of international lidar investigators make measurements of tropospheric and stratospheric aerosol. Some of these members are also members of the NDSC network. The SAGE III project will coordinate with different investigators to facilitate the collection of lidar profiles during periods identified as being within the sampling criterion for correlative measurement opportunities. These facilities will be especially useful following a recent volcanic eruption to help track the global dispersion of volcanic aerosol layers.

Russian Measurement Network Aerosol, ozone, and nitrogen dioxide observations will be available from sites in Moscow (56° N), Murmansk (69° N), Tomsk (57° N), and a north Caucasus site (44° N). Measurement opportunities from these sites are being coordinated by the Russian members of the SAGE III Science Team.

Additional Ground-based and Balloon-borne Measurement Activities A number of additional facilities exist around the globe that are not associated with the organizations listed above, but can provide correlative measurement data of known quality. The Umkehr and Dobson ozone observational sites and the Atmospheric Radiation Measurement (ARM) field sites are examples of these activities. The SAGE III project will contact these programs as their plans materialize.

The coordination of SAGE III correlative measurements is also being conducted with international partners. Many countries support high altitude balloon instruments that have flight opportunities every year. For example, the BALLAD and RADIBAL are aerosol instruments supported by the Service d'Aeronomie du CNRS (SA) that routinely fly each year. If they are launched at suitable latitudes and periods, they can provide valuable information for the SAGE III/Meteor-3M validation program. Dr. C. Brogniez from University of Lille will be the primary contact for coordinating European correlative measurement opportunities. In addition to these activities, a major measurement field campaign is being organized to support validation of the Japanese ILAS-II and the European ENVISAT-1 satellite instruments in early 2002 (see below). Drs. Chu, Thomason, and Trepte from the SAGE III Science Team are guest investigators on these different validation programs and will facilitate comparisons with SAGE III data.

5.3 Existing Satellite Data

Initial intercomparison studies will rely heavily upon the climatology of the constituent distributions and archived satellite data sets. These studies will be augmented with valuable intercomparisons during near measurement coincidences between SAGE III and SAGE II, HALOE, and POAM III satellite occultation events. Figure 3 displays a map of the predicted satellite locations for these satellites in 1999 to illustrate the possible frequency of overlap periods between instruments. These intercomparisons should provide one of the best assessments of relative measurement accuracy because of the similarity in instrument designs, measurement geometry, and the extensive correlative measurement comparison records available for each instrument.

An important cross-calibration activity that has been previously useful for SAGE II validation studies is available when sunrise and sunset occultation events take place near the same latitude of each other. These measurement intersections will occur approximately 6 times a year for SAGE II and about 10 times a year for HALOE. For the SAGE III/Meteor-3M mission, a similar sunrise/sunset comparison will not be available because the orbital parameters for this mission restrict the sunrise events to the Northern Hemisphere and sunset events to the Southern Hemisphere (Fig. 3). The absence of intersection opportunities will require the use of a transfer standard to assess possible biases between the two solar measurement events. It is envisioned that comparisons between observations from either SAGE II or HALOE with those from SAGE III will provide this reference check. For comparisons with SAGE II, near coincident intersections with SAGE III occur only in the summer hemisphere. As a result, this calibration check will require that the SAGE II instrument remains operational for at least 1 year following the launch of SAGE III. For SAGE III/Meteor-3M lunar events, cross calibration opportunities will exist with other SAGE III solar events. These opportunities will occur about 10 times each year and offer an excellent opportunity to examine possible biases in lunar transmission profiles and derived ozone products.

Intercomparisons with other current satellite instruments are also planned and are listed in Table 4. This list is not intended to be comprehensive, but is meant to give a flavor for the breadth of satellite correlative measurement opportunities available. Comparisons between SAGE III; GOMOS, MIPAS, SCIAMACHY on the European ENVISAT satellite; and ILAS on the Japanese ADEOS II satellite should be especially valuable for validation studies. Trajectory tools will also be employed in comparison studies between satellite measurements to enhance the number of coincident measurement opportunities. Several members of the SAGE III Science Team are members on validation teams for these the two satellite platforms and will have access to and participate in discussion on their science and validation data sets.

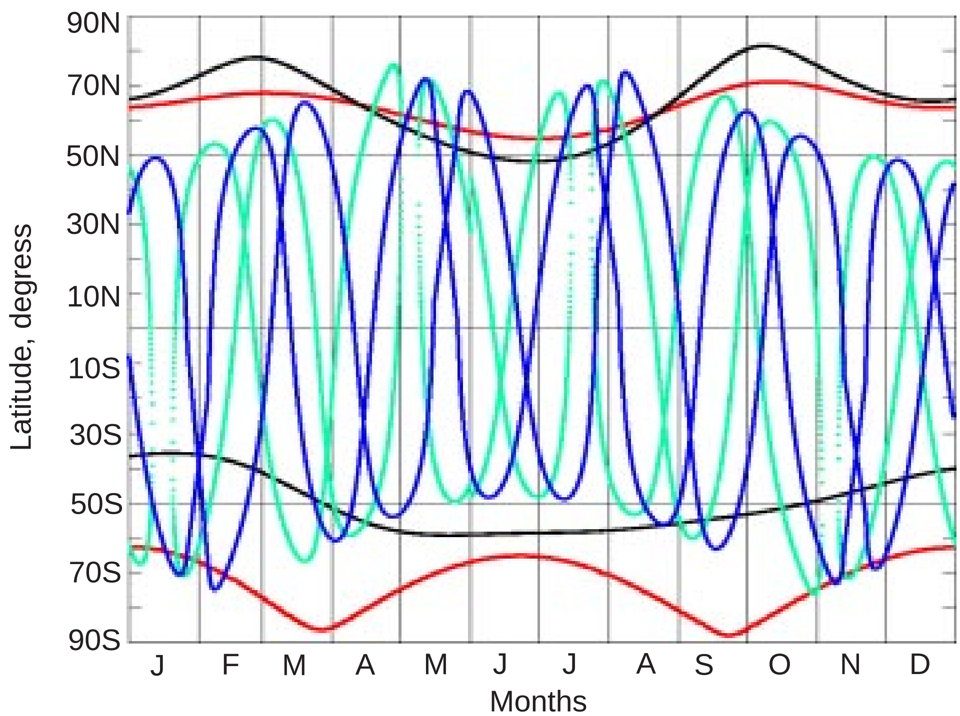

Figure 3. Representative latitude coverage for SAGE III (black), SAGE II (blue), HALOE (green), and POAM III (red) satellite experiments.

Table 4. Concurrent Satellite Experiments with SAGE III/Meteor-3M

Satellite/ Observations	Period	Latitude Coverage
SAGE II (ERBS) • 1.02, .525, .452, & .385 µm aerosol extinction • O_3, NO_2, H_2O	October 1984 - present	80°N - 80°S (seasonally dependent)
HALOE (UARS) • 2.45, 2.8, 3.4, 3.46, & 5.26 µm aerosol extinction • O_3, NO_2, H_2O	September 1991 - present	80°N - 80°S (seasonally dependent)
MLS (UARS) • O_3, H_2O, ClO • temperature & pressure	September 1991 - Present (operating intermittently)	global
SBUV 2 (NOAA polar orbiters) • O_3 conc.	1989 - 1994; 1996 - present	80°N - 80°S (sunlit portion)
GOME (ERS-2) • O_3, OClO, NO_2, BrO	1995 - present	global
POAM III (SPOT 4) • 1.02, .922, .779, .442, & .353 µm aerosol extinction • O_3, NO_2, H_2O • temperature & pressure	April 1998 - present	Sunrise: 55°N -71°N Sunset: 63°S -88°S
ILAS II (ADEOS II) • .780, 7.16, 8.27 10.60 & 11.76 µm aerosol extinction • O_3, NO_2, H_2O • temperature and pressure	Launch: Nov. 2001	Sunrise: 56°N -70°N Sunset: 63°S -88°S
GOMOS (ENVISAT) • aerosol extinction (IR to UV) • O_3, H_2O, NO_2, NO_3, BrO, OClO • temperature & pressure	Launch: July 2001	Global
MIPAS (ENVISAT) • aerosol extinction (IR) • O_3, NO_2, H_2O	Launch: July 2001	Global
SCIAMACHY (ENVISAT) • aerosol extinction (IR to UV) • O_3, H_2O, NO_2, NO_3, OClO temperature & pressure	Launch: July 2001	Nadir view: Global Limb view:
SABER (TIMED) • O_3, H_2O • temperature	Launch: Summer 2001	Limb view: near Global

5.4 Airborne Measurement Activities

Although considerable progress can be made towards the validation of SAGE III data products through comparisons with other satellite missions and ground-based instrument networks, concurrent correlative measurements are still needed to assess many of the requirements identified in section 3.2.

Until launch preparations for the SAGEIII/Meteor-3M mission reach a more refined stage of maturity, detailed planning activities for another NASA airborne correlative measurement campaign will be deferred. It is hoped that an SAGE III airborne mission can be coordinated with field measurement activities needed for ENVISAT and ADEOS II validation that are scheduled for November–March 2002 at mid and high latitude locations. The NASA DC-8, ER-2 and WB-57F aircraft are presently being considered. Selection of an aircraft platform and instrument suite will also be deferred until the summer of 2000 and a plan can be formulated based on results from SOLVE and integrated with NASA's Research and Analysis programs. A NASA Research Announcement will be released for any future aircraft mission.

5.5 Validation Strategy by Species

Aerosols

SAGE III aerosol extinction measurements will be validated by using comparisons with other satellite extinction measurements and derived observations from a variety of instruments (e.g. Russell et al., 1981). Comparisons between SAGE II and SAGE III will be particularly useful over all height ranges. Comparisons with POAM III, on the other hand, will be used primarily above 20 km. At lower heights, there are some unexplained differences between SAGE II and POAM III extinction (and other species) measurements that may reflect differences in the sensor design that are accentuated when atmospheric refraction effects become large. As a result, SAGE III validation will require additional aerosol measurements below 20 km to better understand these differences.

There are a large number of instruments that provide information on aerosol microphysical and optical properties. Lidar backscatter profile measurements have been used in previous measurement campaigns for the validation of SAM II, SAGE I, and SAGE II aerosol observations. Derivation of aerosol extinction from lidar data first requires application of a careful normalization procedure and extraction of the Rayleigh scattering contribution. Since Rayleigh scattering is derived from knowledge of atmospheric density (via temperature), large uncertainties in the lidar profiles can be introduced by uncertainties in the meteorological profile data. Best stratospheric lidar measurements can be obtained with contemporaneous temperature information. Conversion of the lidar backscatter profiles to extinction profiles also requires knowledge of the aerosol backscatter-to-extinction coefficient. In the stratosphere, this factor is fairly well known, but can vary substantially in the troposphere depending upon the aerosol composition. For validation, it is desirable to have lidar measurements at multiple wavelengths to match the spectrum of measurements made by SAGE III. In addition, depolarization measurements are useful for discriminating between spherical and non-spherical particles.

Since SAGE III Science Products will be used to infer aerosol surface area, measurements of the aerosol size distribution from 0.01 - 5 μm will be needed for validation. It is believed that a combination of lidars, particle counters, and other instruments on aircraft and balloon platforms will be needed with satellite measurements for validation of the SAGE III aerosol products.

Ozone

Validation of SAGE III ozone concentration profiles will consist of comparisons with ground-based, balloon-borne, airborne and satellite measurements. Principal comparisons will focus on

SAGE II, HALOE, MLS, and POAM III satellite measurements. These comparisons should permit an assessment of ozone concentration to an accuracy of <10% for most of the stratosphere. Ground-based microwave and lidar profile measurements at Ny, Alesund, Norway and Lauder, New Zealand will augment correlative satellite data in the upper stratosphere and mesosphere. In the lower stratosphere and upper troposphere, satellite measurements typically have larger uncertainties than at higher altitudes and SAGE III validation will be based upon comparisons with ECC ozonesondes and aircraft measurements.

Measurements are needed to assess the horizontal and vertical variability of stratospheric ozone over the slant path from aircraft flight altitude to at least 50 km. Measurements should have a vertical resolution of at least 1/2 km and horizontal resolution of 10 km. This requirement can be partially achieved with a zenith-viewing DIAL lidar system on the DC-8 tuned for stratospheric ozone concentrations. Contemporaneous measurements from an airborne chemilumenescnene instrument are also desired to tie the lidar observations to the flight level. For higher altitudes, a combination of ground-based lidar and microwave measurements will be needed. These measurements also need to be compared with UV photometer measurements during coincident balloon flights to maintain traceability to the standard reference technique. It is especially important to acquire correlative measurements during both solar and lunar events and also at high and low latitudes where ozone distributions in the stratosphere and troposphere are considerably different.

Water Vapor

Although water vapor measurements in the upper troposphere and lower stratosphere have been conducted since the late 1940s, considerable disagreement remains between different techniques. Initial comparisons will be based upon SAGE III and HALOE, MLS, and POAM III measurement coincidences. In addition to these comparisons, it is desirable to have contemporaneous correlative measurements take place with a variety of water vapor sensors (e.g., frost point hygrometers, lidar, etc.) to bracket the range of uncertainty among each technique. Because of the highly variable nature of water vapor, measurements are needed along the LOS, especially in the upper troposphere where variations are expected to be significant. Airborne lidar systems have sufficient horizontal resolution, accuracy and precision to satisfy this objective.

Nitrogen Dioxide

Validation of SAGE III measurements of NO_2 is inherently difficult because it is rapidly photolyzed during local sunrise and quickly regenerated through reactions of NO with O_3 and ClO during local sunset. For instance, changes in the abundance of NO_2 can occur by a factor of 2-3 with a variation of the solar zenith angle from 85° to 90°. This rapid change in NO_2 concentration can introduce significant inhomogeneities along the SAGE III slant path that must be accounted for in order to retrieve an accurate value of NO_2 concentration. Corrections for this effect will require:

1. an accurate model description of the variation of NO_2 at sunrise and sunset

2. validation of the model with in situ measurements of the diurnal variation of NO_2 under varying conditions, and

3. verification of this method of correction by comparison with coincident in situ measurements, preferably during sunrise and sunset.

Because the development and validation of this diurnal correction model is external to the SAGE III measurement and algorithm retrieval system, no such correction is applied to the Standard Data Products. Application of the diurnal correction model to the satellite observations is essential, however, for comparisons with in situ measurements.

A more fruitful validation approach for SAGE III measurements of NO_2 will be based upon comparisons of the integrated slant path abundances which will eliminate the need for the diurnal correction. This will include comparisons between near coincident observations by SAGE III and SAGE II (sunset events only), POAM III, or HALOE. Additional measurement opportunities will be available following the launch of ENVISAT and ADEOS II. Balloon observations (e.g., Mark IV instrument) can also provide valuable correlative measurement information; however, these measurements are infrequent and can be complicated by uncooperative meteorological conditions.

Chlorine Dioxide

SAGE III OClO observations are a new measurement for the SAGE instrument family and will be performed at night with lunar occultation. OClO is primarily produced in the winter polar vortex through reactions involving BrO and ClO. Correlative measurements of these species are, thus, needed at twilight and for a short period before sunrise or after sunset. Column correlative measurements are available from ground-based instruments from NDSC sites at Ny Alesund and Eureka. Spaceborne correlative measurements are currently available from the GOME satellite instrument and will be available from the SCIAMACHY satellite instrument in 2001.

Nitrogen Trioxide

NO_3 is formed predominantly via the reaction

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \qquad (2)$$

with a minor production channel through the thermal decomposition of N_2O_5 and removed during the daytime by photolysis. Since the rate of reaction (2) is relatively slow at stratospheric temperatures, concentrations of NO_3 are negligible during daylight hours. At night removal of NO_3 is mainly limited to reaction with NO_2 to produce N_2O_5 via

$$NO_3 + NO_2 + M \rightarrow N_2O_5 + M. \qquad (3)$$

In the lower stratosphere thermal decomposition is too slow to be significant, and the steady-state expression for NO_3 indicates that NO_3 abundance is most directly controlled by O_3, i.e.,

$$NO_3|_{ss} = k_8O_3/k_9M. \qquad (4)$$

At high latitudes, nighttime measurements of O_3 and temperature may, therefore, be sufficient to check the consistency of the SAGE III lunar NO_3 observations. A ground-based interferometer based at Table Mountain, CA and led by Dr. S. Sander of JPL will provide column NO_3 correlative measurements during satellite overpasses. Development of this instrument for SAGE III validation has been supported by the EOS Validation Program.

Temperature

SAGE III will make temperature profile measurements, a capability not realized by either of its predecessors or by either HALOE or POAM III. These measurements will provide a self-consistent measurement of Rayleigh scattering needed to reduce ozone, nitrogen dioxde, and aerosol uncertainties above 30 km. Temperature profiles also will aid in the interpretation of SAGE III data (e.g. PSC and ozone observations) and help delineate the altitude of the tropopause.

Sounding rockets and airborne lidar systems offer the most promising measurement set for the validation of temperature profiles above 30 km. In support of this effort, the SAGE III Validation Team will seek a set of rocketsonde measurements from launch ranges at either Andoya, Norway or Esrange, Sweden. Measurements will be coordinated with SAGE III overpasses. Airborne lidar temperature measurements are also desirable to reduce errors in coincident times and locations. An added advantage of some of these systems is their ability to obtain simultaneous measurements of ozone, aerosol and temperature; and thus, provide the essential data set to evaluate improvements of SAGE III temperature measurements on ozone and aerosol retrievals. Validation of temperature at lower altitudes will also be based on comparison between SAGE III and radiosonde measurements. The comparisons however, may suffer from differences in time and space coincidences due to the fixed launch times of the radiosondes.

Altitude Registration of Transmission Profiles

The accurate determination of the transmission profile is fundamental to the retrieval of all species. For SAGE I, altitude registration errors of about 200 - 400 m resulted in biases in ozone mixing ratio and other species (Wang et al., 1996). For SAGE III, an altitude registration uncertainty of 100 m is desired. An assessment of systematic altitude biases could be achieved by measuring the altitude of the top of an optically thick cloud deck that lies along the slant path. However, cloud features vary considerably over short distances, and a more robust assessment of these errors might be obtained by examining differences in the vertical structure of the measured species. This approach should be especially useful near the tropopause, where strong vertical gradients often exist in these constituent distributions.   Airborne lidar measurements coincident along the SAGE III slant path have the necessary spatial resolution, accuracy, and precision to satisfy this objective. A self-consistency check of the SAGE III lunar transmission profile could be obtained during period of measurement overlap with the solar occultation events.

Cloud Detection

A new product derived from SAGE III aerosol extinction measurements is the ability to detect the presence of optically thin cloud along the LOS from background and aged volcanic aerosol distributions (Kent and McCormick, 1997). Cloud observations along the LOS, consequently, are needed from about 6 km upward to 30 km. This requirement is complicated by the inhomogeneous nature of the cloud, its relatively small structure size compared to the ~200 km path length of the solar ray path through the atmosphere, and the fairly rapid changes that take place within a cloud. To fully satisfy these requirements requires extensive resources beyond the capabilities of most aircraft measurement campaigns. However, considerable insight can be gained from limited observations over the stated altitude range with a vertical resolution of about 100 m and a horizontal resolution of a few hundred meters. An airborne aerosol lidar system with multiple wavelengths would be best suited for achieving these requirements. Radiometeric measurements of the sun from within and through the top of the cloud are also needed to simulate the SAGE III measurement directly. It is also highly desirable to obtain concurrent in situ cloud measurements (i.e., ice-water content, particle size distribution, temperature, etc). Such measurements require multiple flight paths along the LOS at varying altitudes under different cloudiness scenarios.

6. IMPLEMENTATION

The SAGE III data validation effort will be led by Dr. M. Pat McCormick (Principal Investigator) with members of the SAGE III Science Team, project engineers, mission operations and algorithm development personnel, and correlative measurement investigators. Members of the Science Team will be responsible for the validation of each Science Standard Product. Table 2 lists the leaders and members of the different validation working groups. Dr. Chip Trepte of NASA LaRC will serve as the primary point-of-contact for coordinating the correlative measurement activities.

Findings from these studies will be reviewed by the SAGE III Science and Algorithm Development Teams. During the first year of operation, revisions to the SAGE III software algorithm and production of the Science Data Products will take place as needed. Findings from the validation studies will be reported in the scientific literature.

The validation strategy outlined in this plan is subject to change as conditions warrant. The Science Team will review its status at each Science Team Meeting (or as needed) and make appropriate changes.

7. SUMMARY

A validation strategy for the SAGE III Standard Science Data Products has been developed that embraces two different approaches. The first approach will be directed toward the evaluation of the retrieval process through a comparison of results from a SAGE III forward model with those from the inverse retrieval algorithm. Additional activities will be based on self-consistency checks using internal instrument and engineering data.

The other approach focuses on the collection of independent correlative measurements to intercompare and verify the accuracy of SAGE III Standard Science Products. Primary comparisons will be based upon a large number of coincidences between satellite, ground-based, and balloon-borne correlative measurements. Comparison techniques employing isentropic trajectories will also be used to enhance the number of coincidences between satellite and correlative measurement sites. Although these activities will provide considerable insight into relative biases between instrument measurements, aircraft observations are still needed along the satellite-sun line-of-sight to assess fundamental assumptions in the retrieval algorithm.

The unfortunate loss of correlative measurement opportunities for SAGE III during the SOLVE mission was due to a launch delay of the SAGE III/Meteor-3M platform. Intercomparisons between POAM III and airborne instrument measurements made during SOLVE will help assess biases between instruments and identify new validation approaches. After SAGE III is launched, intercomparisons between SAGE III and other satellites will benefit from the intense comparison effort made during SOLVE. Satellite intercomparisons alone, however, will not be sufficient for evaluating SAGE III products in the lowest layer of the stratosphere and upper troposphere where changes in ozone, water vapor, and aerosols have important impacts on climate. Additional airborne, balloon-borne, and ground-based correlative measurements will be needed to satisfy the SAGE III validation requirements.

8. REFERENCES

Chu, W.P., and M.P. McCormick, 1979: Inversion of stratospheric aerosol and gaseous constituents from spacecraf solar extinction data in the 0.38-1.0 micron wavelenght region, Appl. Opt., 18, 1404-1413.

Cunnold, D.M., M.C.Pitts, and C.R.Trepte, 1984: An intercomparison of SAGE and SBUV ozone observations for March and April 1979, J. Geophys. Res., 89, 5249-5262.

Cunnold, D.M., W.P. Chu, R.A. Barnes, M.P. McCormick, and R.E. Veiga, 1989: Validation of SAGE II ozone measurements, J. Geophys. Res., 8447-8460.

Gibbons, J.D., 1985: Nonparametric methods for quantitative analysis, in American Series in Mathematical and Management Sciences, 2nd ed., Vol. II, Columbus, Ohio.

Gille, J.C., S.T. Massie, and W.G. Mankin, Preface: Evaluation of the UARS Data, J. Geophys. Res., 101, 9539-9540,1996.

Logan, J.A., 1999: An analysis of ozonesonde data for the troposphere: recommendations for testing 3-D models and development of a gridded climatology for tropospheric ozone, J. Geophys. Res., 104, 16115-16149.

NASA EOS Science Plan: The State of Science in the EOS Program, ed. M.D. King, NASA NP-1998-12-069-GSFC.

NASA EOS Reference Handbook: A guide to NASA's Earth Science Enterpirse and the Earth Observing System,

Pierce, R.B., J. Grooss, W.L. Grose, J.M. Russell, P.J. Crutzen, T.D. Fairlie, and G. Ligenfelser, 1997: Photochemical calculations along air mass trajectories during ASHOE/MAESA, J. Geophys. Res., 102, 13153-13167.

Rind, D., E.-W Chiou, W. Chu., S. Oltmans, J. Lerner, J. Larsen, M.P. McCormick, and L. McMaster, 1993: Overview of the Stratospheric Aerosol and Gas Experiment II water vapor observations: method, validation, and data characteristic, J. Geophys. Res., 98, 4835-4856.

Russell, P.B. et al., 1981b: Satellite and correlative measurements of the stratospheric aerosol, II, comparison of measurements made by SAM II, dustsondes and an airborne lidar, J. Atmos. Sci., 38, 12295-1312.

Russell, P.B., T.J. Swissler, M.P. McCormick, W.P. Chu, J.M. Livingston, and T.J. Pepin, 1981a: Satellite and correlative measurements of the stratospheric aerosol, I, an optical model for data conversions, J. Atmos. Sci, 1279-1294.

Russell, P.B., and M.P. McCormick, 1989: SAGE II Aerosol data validation and initial data use: an introduction and overview, J. Geophys. Res., 94, 8335-8338.

Wang, H.J., D.M. Cunnold, and X. Bao, 1996: A critical analysis of Stratospheric Aerosol and Gas Experiment ozone trends, J. Geophys. Res., 101, 12495-12514.

World Meteorological Organization (WMO), 1991: Third WMO intercomparison of the ozone-sondes used in the global ozone observing system, Global atmosphere watch, WMO Rep. 27, Geneva.

9. POINTS OF CONTACT

Dr. Charles (Chip) Trepte
SAGE III Validation Coordinator
Radiation and Aerosols Branch, MS 475
NASA Langley Research Center
Hampton, VA 23681-2199
(757) 864-5836
FAX: (757) 864-2671
c.r.trepte@larc.nasa.gov

Dr. M. Patrick McCormick
Principal Investigator
Center for Atmospheric Sciences
23 Tyler Street
Hampton University
Hampton VA 23668
(757) 728-6867
FAX: (757) 727-5090
pat.mccormick@hamptonu.edu

Dr. William (Bill). P. Chu
SAGE III Project Scientist
Radiation and Aerosols Branch, MS 475
NASA Langley Research Center
(757) 864-2675
FAX: (757) 864-2671
w.p.chu@larc.nasa.gov